SPATIALLY DISCRETE MULTI-LOOP RF-DRIVEN PLASMA SOURCE HAVING PLURAL INDEPENDENT ZONES

BACKGROUND

1. Technical Field

The disclosure relates to RF-driven plasma sources for reactors employed in plasma processing of workpieces such as semiconductor wafers.

2. Background Discussion

In plasma processing of workpiece, such as a semiconductor wafer, there is a need for a plasma source capable of providing a high plasma ion density and, simultaneously, a low plasma sheath ion energy to an extent that is currently unavailable. A high plasma ion density is needed for improved processing rate and productivity. A reduced plasma ion energy is needed for reduced plasma ion energy in order to prevent contamination from ion bombardment of metal surfaces near the plasma sheath. Reduced ion energy may also reduce ion bombardment damage to semiconductor device features. Such features are becoming extremely small and more susceptible to such damage, thus requiring reduction in plasma electron energy.

A basic problem is that plasma sources capable of providing high density plasma also produce relatively high energy plasma ions. The reason is that such sources couple relatively high electric fields to the plasma, raising the plasma sheath voltage. High plasma sheath voltages impart high energy to plasma ions in the plasma sheath. This produces ion bombardment of metal surfaces adjacent the plasma sheath, which produces metal contamination. An inductively coupled plasma source employs an RF-driven coil antenna, which has a capacitance that couples a high voltage to the plasma, contributing to the high plasma sheath voltage. A capacitively coupled plasma source employs an RF-driven electrode which has an even greater tendency to couple high voltage to the plasma. Toroidal plasma sources produce plasma densities somewhat less than inductively coupled plasma sources.

What is needed is a plasma source capable of producing a plasma having an ion density as great as or exceeding that of a conventional inductively coupled plasma source, and with a minimum plasma ion energy less than (or not exceeding) that of conventional plasma sources.

SUMMARY

A plasma reactor comprises a processing chamber including a ceiling, and a resonator having an axis of symmetry transverse to the ceiling, the resonator comprising: (a) inner and outer return cylinders and an intermediate return cylinder between the inner and outer return cylinders, (b) inner and outer RF-driven cylinders adjacent inner and outer surfaces, respectively, of the intermediate return cylinder, (c) the inner and outer return cylinders and the inner and outer RF-driven cylinders contacting the ceiling.

The reactor further comprises first and second RF power generators coupled to respective ones of the inner and outer RF-driven cylinders, and inner and outer pluralities of reentrant conduits on a side of the ceiling external of the processing chamber, the inner and outer pluralities of reentrant conduits disposed, respectively, in inner and outer concentric zones of the ceiling.

In an embodiment, each of the plural reentrant conduits extends in a radial direction. The plasma reactor may further comprise a plasma distribution controller adapted to govern a ratio between power output levels of the first and second RF power generators.

In one embodiment, the ceiling comprises, for each respective reentrant conduit of the inner and outer pluralities of reentrant conduits, a pair of ports extending through the ceiling and coupled to opposite ends of the respective reentrant conduit.

In an embodiment, the ceiling comprises an internal gas manifold and gas injection orifices coupled to the gas manifold, while the plasma reactor further comprises a process gas supply and a gas supply conduit coupled to the internal manifold and extending axially from the internal manifold and through an interior volume of the hollow center ground cylinder to the process gas supply. In a related embodiment, the gas injection orifices comprise openings facing an interior of the processing chamber.

In one embodiment, the plasma reactor further comprises a coolant supply, internal recirculation passages in the ceiling and a coolant supply conduit coupled to the internal recirculation passages and extending axially from the ceiling and through an interior volume of the hollow center ground cylinder to the coolant supply.

In an embodiment, each of the plural reentrant conduits comprises a conductive main portion and an insulating ring-shaped break.

In one embodiment, each of the ports has a width along a direction transverse to the path that exceeds a diameter of the respective one of the plural reentrant conduits. In a related embodiment, each of the reentrant ports has a cross-sectional shape that is one of: circular, oval, rectangular, kidney-shaped.

In one embodiment, the resonator has an axial length corresponding to a half wavelength of RF current or RF voltage produced by the RF power generator.

A related embodiment further includes a cap covering and contacting top edges of the inner, outer and intermediate return cylinders. Further, the inner and outer RF-driven cylinders are terminated at respective heights below the cap defining respective gaps between the inner and outer RF-driven cylinders and the cap. In a related embodiment, the intermediate return cylinder is terminated at a height above the ceiling defining a separation between the intermediate return cylinder and the ceiling.

Optionally, there may be provided an RF bias power generator having an output terminal coupled to the workpiece support and a return terminal coupled to the ceiling.

In an embodiment, a first plurality of legs are connected between the first RF power generator and respective first points on the inner RF-driven cylinder, and a second plurality of legs are connected between the second RF power generator and respective second points on the outer RF-driven cylinder.

In a related embodiment, the respective first points are located on a top edge of the inner RF-driven cylinder and the respective second points are located on a top edge of the outer RF-driven cylinder.

In a further embodiment, there is provided a first shield enveloping a portion of each of the first plurality of legs and a second shield enveloping a portion of each of the second plurality of legs.

In one embodiment, the ceiling contacts respective bottom edges of the inner and outer return cylinders and respective bottom edges of the inner and outer RF-driven cylinders.

In one embodiment, the inner and outer concentric zones of the ceiling are divided at a circular border corresponding to the intermediate return cylinder.